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Interpolation Errors in Spectrum Analyzers

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INTERPOLATION ERRORS IN SPECTRUM ANALYZERS

I. INTRODUCTION

One of the core tools used in electromagnetic compatibility/electromagnetic interference (EMC/EMI) is the spectrum analyzer. A spectrum analyzer is a tunable receiver that can sweep over a broad range of frequencies. With a transducer such as an antenna or a current probe, the spectrum analyzer can be used to measure electromagnetic fields as a function of frequency. For accurate results, the spectrum analyzer must have the trace data adjusted for the particular transducer to obtain the proper measurement amplitude over a given frequency range. This is done using a transducer factor that is defined as the ratio of the field presented to the transducer to the voltage developed by the transducer at its end connector.[1] An example of a transducer factor is shown in figure 1.

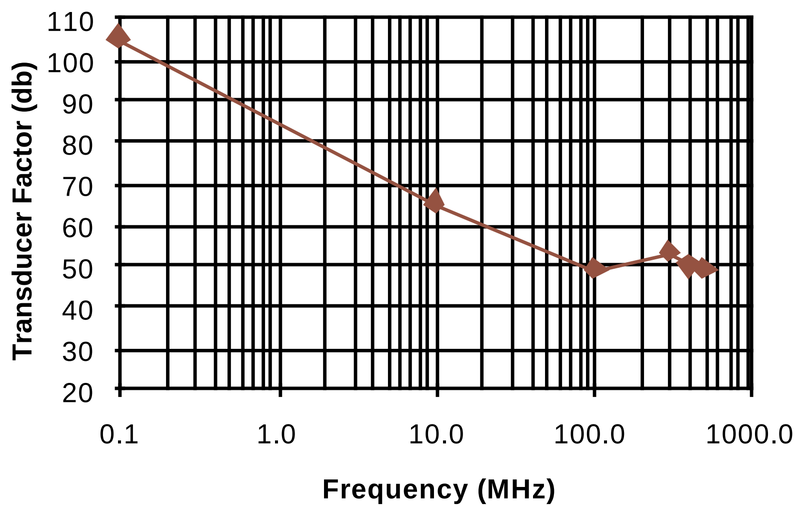

Figure 1. Transducer factor for a 6-cm loop probe.

Transducer factors are entered into the spectrum analyzer as amplitude-correction factors. Amplitude corrections provide an easy way to adjust trace data with a set of amplitude and frequency parameters while the spectrum analyzer is sweeping the measurement range. Every measurement sweep of data is adjusted by the amplitude-correction values. Amplitude-correction data are constructed from left to right and are created by entering frequency and amplitude values into an amplitude-correction table. The frequency and amplitude values specify a coordinate point from which amplitude-corrections are linearly interpolated.[2]

II. INTERPOLATION ERRORS

The transducer factors for a number of probes are on semilogarithmic scales which, if the user is not careful, can lead to an error on most spectrum analyzers due to their linear display. Suppose the plot in figure 2, a –40 dB/decade slope, was the transducer factor for a probe to be entered into the spectrum analyzer.

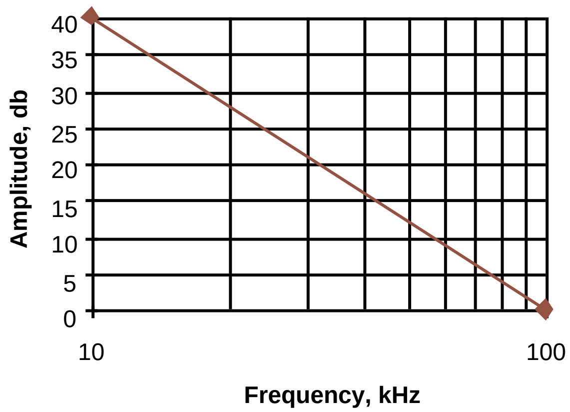

Figure 2. Sample transducer factor.

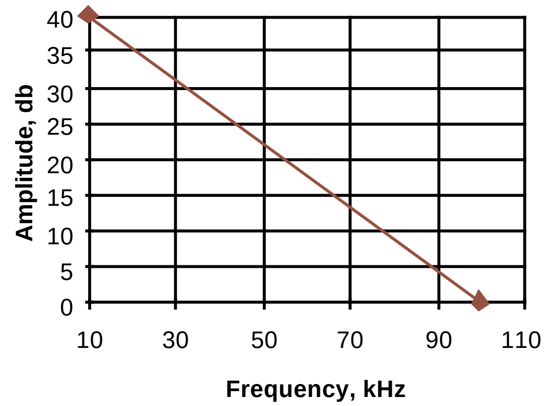

Figure 3. Amplitude-corrected display.

If the two most obvious points, the end points, are used to enter the amplitude-correction factor into the spectrum analyzer for the probe, then the display would resemble figure 3. At a glance this looks correct, but remember the display's linearity. Table 1 shows the data points along the lines of both figures 2 and 3 for a given set of frequencies. It also shows the interpolation error that is defined as the difference in magnitude for the specified frequency coordinates between the two lines. Here the problem is realized because a –40 dB/decade slope inputted into the spectrum analyzer using two data points would produce an error in amplitude by as much as 10 dB due to the linear interpolation of the spectrum analyzer.

Table 1. Data points for figures 2 and 3 with error.

Frequency (kHz)	Amplitude-Correction Factor	Transducer Factor	Interpolation Error
10	40	40	0
12.5	38.9	36.1	2.8
15	37.8	33	4.8
17.5	36.7	30.3	6.4
20	35.6	28	7.6
25	33.3	24.1	9.2
30	31.1	20.9	10.2
35	28.9	18.2	10.7
40	26.7	15.9	10.8
45	24.4	13.9	10.5
50	22.2	12	10.2
55	20	10.4	9.6
60	17.8	8.87	8.93
65	15.6	7.48	8.12
70	13.3	6.2	7.1
75	11.1	5	6.1
80	8.89	3.88	5.01
85	6.67	2.82	3.85
90	4.44	1.83	2.61
95	2.22	0.891	1.33
100	0	0	0

III. REDUCING INTERPOLATION ERRORS

The interpolation error can not be completely eliminated because that would require an infinite number of data points along the transducer factor to be entered into the spectrum analyzer. Most spectrum analyzers are limited to the number of data points that they can store, so a maximum tolerance of error needs to be established. The maximum tolerance is a limit for the greatest margin of acceptable interpolation error to be determined by the user. For this report, 3- and 1-dB maximum errors were chosen.

The most efficient way to reduce the error is to find the minimum number of data points to enter into the spectrum analyzer to get within the maximum tolerance of error. If the transducer factor is on a semilogarithmic scale, then the data points should be as evenly spaced as possible along this scale and not just at the major divisions or change of slope points. Remember that a slope taken from a semilogarithmic scale and placed on a linear scale will create a curved line, with the majority of the curvature lying in the first half of the linear scale. The spectrum analyzer, however, interpolates linearly between the data points creating the interpolation error. Evenly spacing the points along the transducer factor ensures that some of the data points would be placed in the curve. Having more points in the curve allows the linear interpolation of the spectrum analyzer to better simulate the curve, as will be shown. This not only reduces the interpolation error, but it evens out the error distribution on the spectrum analyzer.

Suppose again that figure 2, a –40 dB/decade slope, is the transducer factor for a probe to be entered into the spectrum analyzer as an amplitude-correction factor using two data points. The plot of the amplitude-correction factor entered into the spectrum analyzer and the semilogarithmic transducer factor on the same linear scale are shown in figure 4. The error between the plots is shown in figure 5.

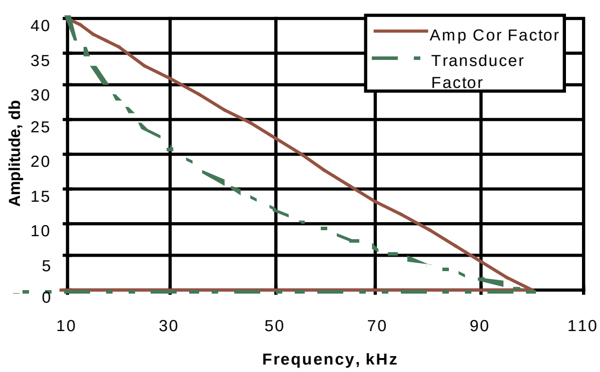

Figure 4. Comparison between amplitude-correction and transducer factors with two points.

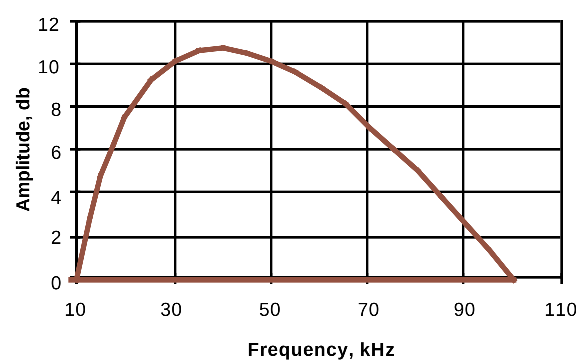

Figure 5. Error between amplitude-correction and transducer factors with two points.

The same plots are repeated for three, four, five, and six amplitude-correction data points along the transducer factor to illustrate how more points will reduce that error. Figures 6, 8, 10, and 12 show the plots of the amplitude-correction factor entered into the spectrum analyzer and the semilogarithmic transducer factor on the same linear scale. Figures 7, 9, 11, and 13 represent the error between the relevant plots.

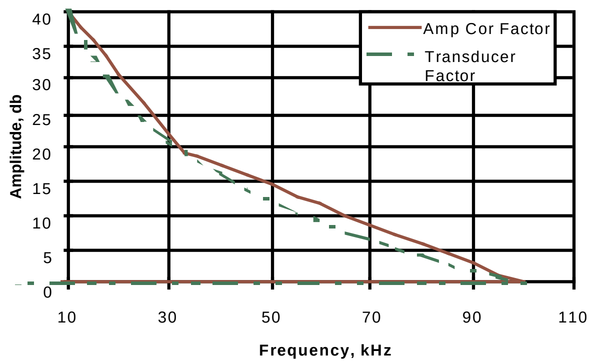

Figure 6. Comparison between amplitude-correction and transducer factors with three points.

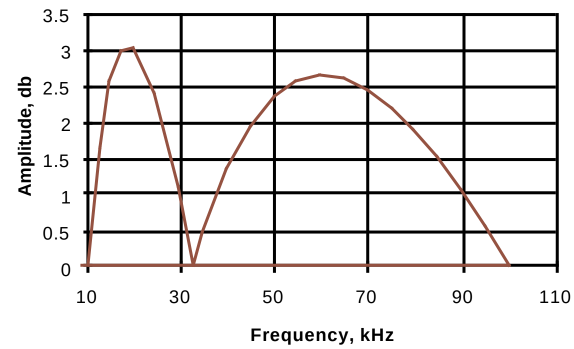

Figure 7. Error between amplitude-correction and transducer factors with three points.

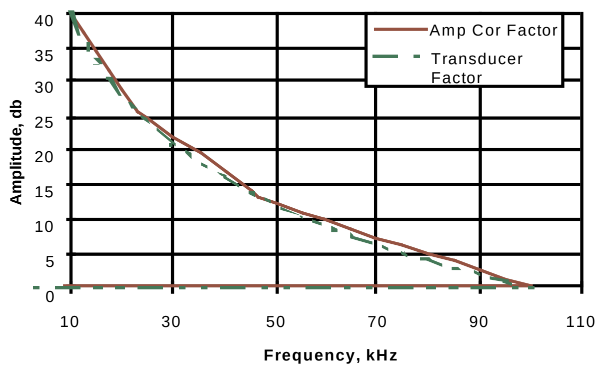

Figure 8. Comparison between amplitude-correction and transducer factors with four points.

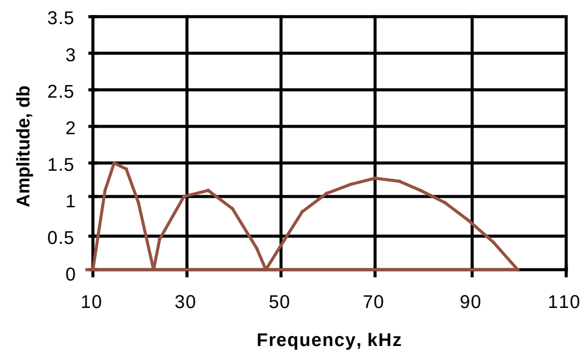

Figure 9. Error between amplitude-correction and transducer factors with four points.

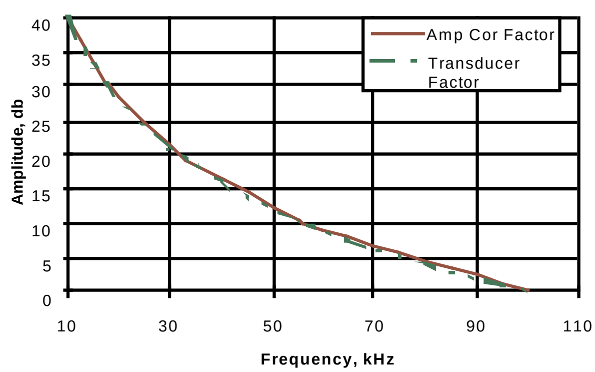

Figure 10. Comparison between amplitude-correction and transducer factors with five points.

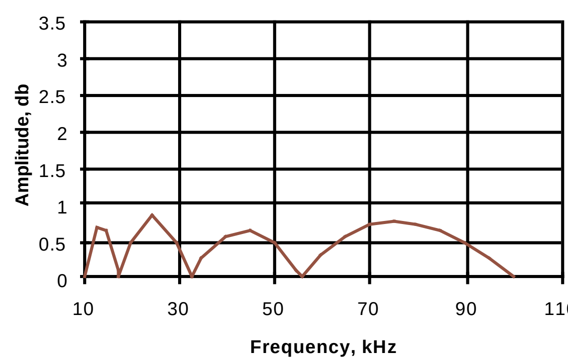

Figure 11. Error between amplitude-correction and transducer factors with five points.

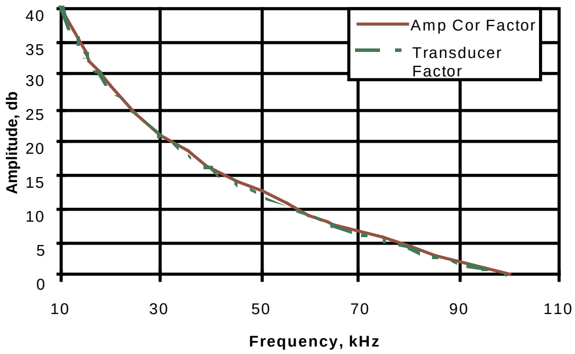

Figure 12. Comparison between amplitude-correction and transducer factors with six points.

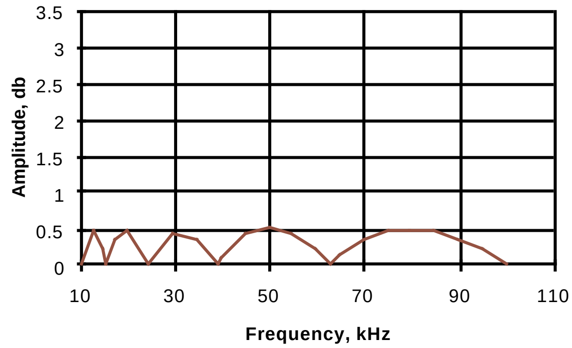

Figure 13. Error between amplitude-correction and transducer factors with six points.

Using these data, it can be determined that it takes three amplitude-correction data points along a –40 dB/decade sloped transducer factor to get within 3 dB of error on the spectrum analyzer. Five amplitude-correction data points are required to get within 1 dB of error.

IV. RESULTS AND CONCLUSIONS

The interpolation errors created by entering amplitude-correction factors into a spectrum analyzer from transducer factors is easily overlooked. It can cause severe changes in results that, if not recognized as being wrong, could go undetected. The error is significantly reduced with little inconvenience to the user by entering more data points from the transducer factor into the amplitude-correction table.

The example in this report was for a single slope over one decade. Spanning more than one decade would create larger interpolation errors between the transducer factor and the amplitude-correction factor requiring more data points to acquire the maximum tolerance of error. If a slope spans more than one decade, enter the points on a decade by decade basis to avoid the larger errors. Any slope that does not span a decade would naturally require fewer points to achieve the maximum tolerance of error. This report does not address this issue, however, the data within gives a good starting point for an educated guess. Table 2 contains the minimum number of data points required to come within the maximum error tolerances of 3 and 1 dB for slopes of –3, –6, –10, –20, and –40 dB per decade.

Table 2. Minimum number of data points to obtain maximum error tolerances.

Slope	Minimum Number of Points Per Decade for 3 dB of Error	Minimum Number of Points Per Decade for 1 dB of Error
–3 dB/decade	2	2
–6 dB/decade	2	3
–10 dB/decade	2	3
–20 dB/decade	3	4
–40 dB/decade	3	5

APPENDIX

A. Test Setup

The goal of the test was to determine how many data points would have to be entered into the spectrum analyzer to bring the interpolation error within the tolerances of 3 and 1 dB. For simplicity, single slopes of –3, –6, –10, –20, and –40 dB per decade were chosen.

The initial data to be compared were generated using a LOTUS 1-2-3 spreadsheet. The spreadsheet compared the slope of a line on a semilogarithmic scale with the same slope on a linear scale for a specified number of data points. The semilogarithmic line represents the transducer factor while the linear line represents the amplitude-correction factor of the spectrum analyzer. The data points are the actual amplitude-correction data points to be entered into the spectrum analyzer. The difference in magnitude for the specified frequency coordinates between the two lines is defined as the interpolation error of the spectrum analyzer.

The Hewlett-Packard model HP 8591E spectrum analyzer used by the Electromagnetic and Environments Branch was chosen to verify the spreadsheet data. A signal generator connected to the spectrum analyzer, as in figure 14, swept the same frequency range as the spreadsheet with a 100 dBmV signal. Using the "Max Hold" function of the HP 8591E, the trace data were obtained and compared to the spreadsheet. The marker on the spectrum analyzer was used to read the magnitudes for the same frequencies as the spreadsheet. This was done for two, three, four, five, and six amplitude-correction data points for each slope. The results, stated in table 2, proved to be the same as those estimated in the spreadsheet. Also, the plots for a –40 dB/ decade slope are included in section D of this appendix for verification of the spectrum analyzer data.

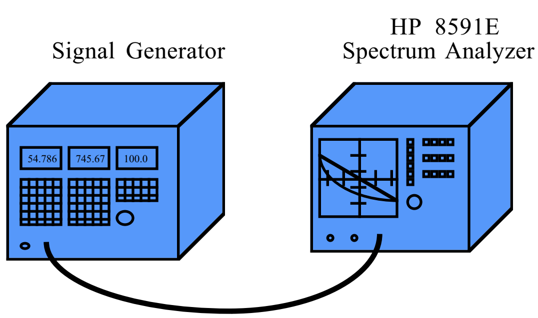

Figure 14. The test setup.

B. Entering Amplitude-Correction Factors

Amplitude corrections provide an easy way to adjust trace data with a set of amplitude and frequency parameters while the spectrum analyzer is sweeping the measurement range. Every measurement sweep of data is adjusted by the amplitude-correction values. Amplitude-correction data are constructed from left to right and are created by entering frequency and amplitude values into an amplitude-correction table. The frequency and amplitude values specify a coordinate point from which amplitude-corrections are interpolated. Up to 79 amplitude-correction data points can be specified for the amplitude-correction table for the HP 8591E.[2]

Note: For purposes of this report, all front panel buttons of the HP 8591E will be designated by bold letters. All display menu buttons will be designated by bold, italic letters.

The following procedure demonstrates how to enter amplitude-correction data into the HP 8591E for a –40 dB/decade slope over the frequency range of 10 to 100 kHz using two amplitude-correction data points:

1. Press **CAL**, ***More 1 of 4, More 2 of 4, More 3 of 4, Amp Cor*** to access amplitude-correction menus.[2]

2. Press ***Edit Amp Cor*** to enter the editing menu.[2]

Note: To clear existing amplitude-correction data, press ***Purge Amp Cor*** two times[2] or use the ***Select Point*** and arrow keys to select the point (or points) to remove using ***Delete Point.***

3. Press ***Select Point***, and move the cursor to point 1 if not already selected (selected points are highlighted on the screen). Enter the first amplitude-correction data point by pressing:

   Select Freq
   10 kHz
   40 +dBm

Note: Notice that the cursor on the signal analyzer display moves from point to frequency to amplitude to the next point automatically. To edit a mistake, use ***Select Point*** to specify the point. Then use ***Select Freq*** or ***Select Amp*** to specify the entry.[2]

4. Enter the second amplitude-correction data point by using the following key sequence:

   100 kHz
   0 +dBm

5. Press ***Edit Done*** when finished. The display of the spectrum analyzer should now resemble figure 3.

C. Saving and Recalling Amplitude-Correction Factors

The transducer factors for some probes span several decades of frequencies as in figure 1. This would require several data points to be entered into the amplitude-correction table of the spectrum analyzer. Fortunately, most spectrum analyzers have the ability to store various amplitude-correction tables. The HP 8591E has enough internal memory to store 52 of these tables. The following procedure explains how to save an amplitude-correction table once it has been entered into the spectrum analyzer:

1. After entering the amplitude-correction table as in section B, press ***Save Amp Cor***.

2. Enter a register number, and then press **Enter** to save the current amplitude-correction table into the spectrum analyzer’s memory.

Note: An amplitude-correction table may also be saved by pressing **Save**, ***Trace-Intrnl***, ***Amp Cor***, and repeating step 2.

When saving several amplitude-correction tables it would be advisable to create a list to remember the register number for each transducer factor. This will aid in recalling the tables. The following procedure explains how to recall an amplitude-correction table:

1. Press **CAL**, ***More 1 of 4***, ***More 2 of 4***, ***More 3 of 4***, ***Amp Cor*** to access the amplitude-correction menus.

2. Press ***Recall Amp Cor***.

3. Enter the register number that the table was saved under, then press **Enter**.

Note: A saved table may also be recalled by pressing **Recall**, ***Internal-Trace***, ***Amp Cor***, and repeating steps 2 and 3 above.

D. Plots of a –40 dB/Decade Slope

The plots in figures 15 through 19 were taken using the HP 8591E spectrum analyzer to verify the computer generated data. These plots are the same as those shown in figures 4, 6, 8, 10, and 12, respectively. The bottom curve represents the transducer factor with a –40 dB/decade slope on a linear scale. It was generated by entering 24 amplitude-correction data points. The top curve is the amplitude-correction factor and illustrates the linear interpolation error of the spectrum analyzer.

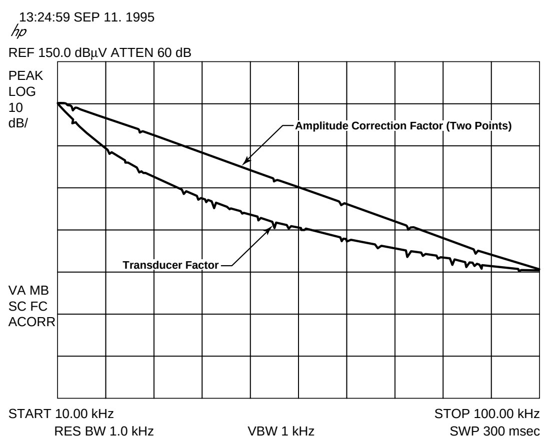

Figure 15. –40 dB/decade slope using two data points.

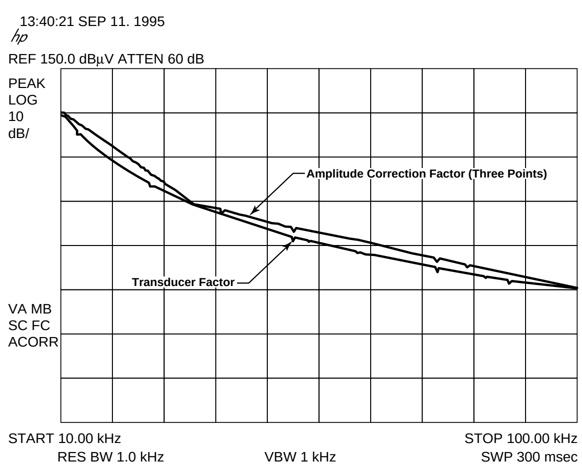

Figure 16. –40 dB/decade slope using three data points.

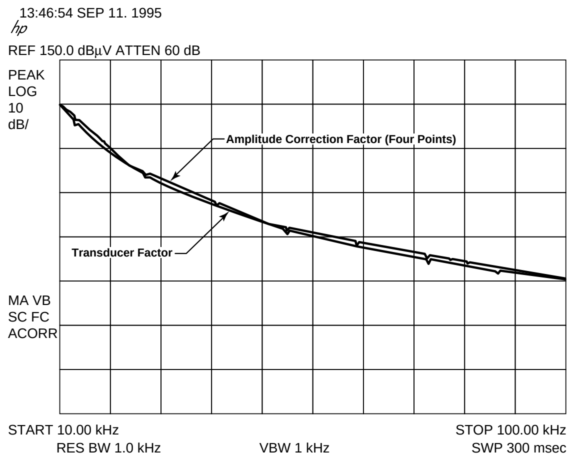

Figure 17. –40 dB/decade slope using four data points.

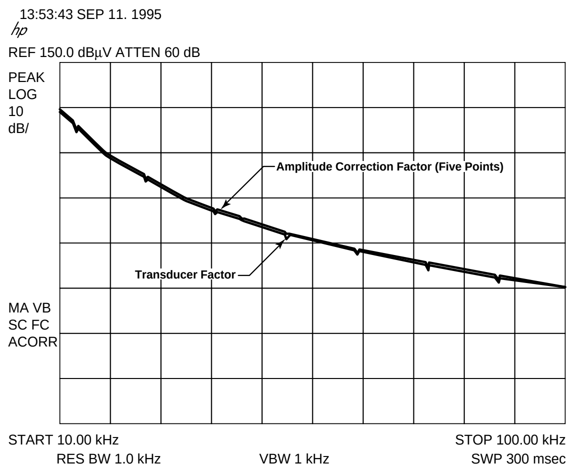

Figure 18. –40 dB/decade slope using five data points.

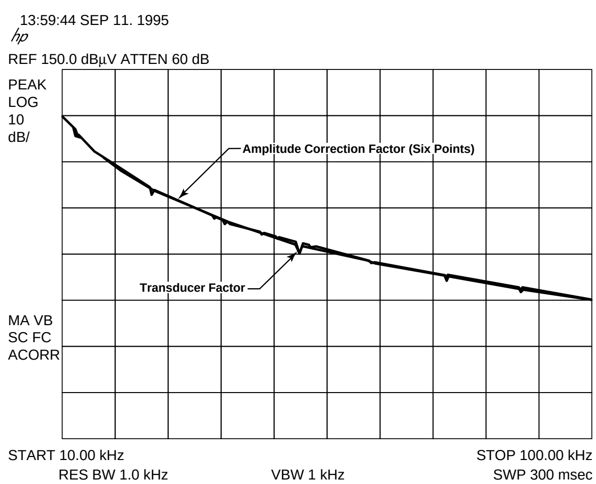

Figure 19. –40 dB/decade slope using six data points.

REFERENCES

1. The Electro-Mechanics Company: “Model 7405 Near-Field Probe Set User’s Manual,” 1991.
2. Hewlett-Packard: “User’s Guide: HP 8590 Series Spectrum Analyzer,” April 1992, pp. 5-33 to 5-37.